# An Evaluation of Offsite Timber Frame Manufacturer's in Wales, UK.

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**Abstract.** STUDENT PAPER. The Knowledge Economy Skills Scholarship two (KESS2) doctoral project undertaken by the first author has contributed research towards work package (WP) four of the Home-Grown Homes project (HGHP) focused on disrupting the challenges that can lead to a supply chain of home-grown timber (UK) for high performance and healthy homes. This paper discusses the element of research within WP4 that has evaluated the manufacturers of timber frame (TF) construction systems manufactured offsite. The Welsh Government's Innovative Housing Programme introduced in 2017 is helping to immensely incentivise the shift to offsite manufacturing (OSM) in Wales where increased systemisation is requiring a profound re-think of how Wales conceives and delivers and shifts towards nearly zero energy dwellings, from 2020. Context to the UK need to drive efficiencies in housing supply and performance is given, highlighting the current and future drivers for the development of OSM. This paper will be of interest to researchers engaged in projects to disrupt conventional thinking and investigating the challenges of using softwood timber, grown and processed offsite, for their own country and export markets within Europe.

**Keywords:** Timber Frame, Offsite Manufacturing (OSM), Building Performance, Performance Gap, Welsh Timber Frame Manufactures.

## 1 Introduction

The European Commission (EC) has always aimed to investigate some of the environmental challenges, such as depletion of natural sources, reducing dependency on non-renewable resources and mitigating climate change [1] particularly in a year which has seen evidence of considerable climate change [2]. Within this contest, the construction sector contributes 42% of final energy consumption, 35% of greenhouse (GHG) emissions, 50% of extracted materials and, in some regions, 30% of water consumption [3]. According to the European provisions, the Welsh government (WG) in 2015 set out the Well Being of Future Generations Act (2015) to share a common vision of a

nation for a sustainable future, with seven pillars of excellence to achieve. Notwithstanding the WG intentions, in 2019 Wales is facing several challenges such climate change, poverty, health inequalities, job security and growth requirements [4] that will affect the actual and the future generations. In this context, woodlands and trees have a role to play in enabling the achievement of various international and domestic climate targets such as the 2015 Paris Agreement on climate change [5]. The construction and the off-site manufacturing (OSM) sectors have the possibility of improving the social, economic, environmental and cultural well-being of Wales [4] with a collaborative and collective approach based on agreed goals and strong general commitments. Given the shortage of housing and the environmental challenges of carbon reduction, cost and speed of build and life-time affordability in energy cost performances, then TF systems more than meets all these pressing needs [6]. The development of the KESS2 doctoral project, co-funded by the European Social Fund (Low Carbon and Materials stream) in collaboration with Woodknowledge Wales (WKW) is presented in this paper, discussing the adoption of innovative engineered timber and OSM techniques in Wales, and the use of TF and their current practice.

## 2 Context to Wales' Timber Supply Chain

Wales, with 14.3% (306,285 ha) of woodland cover in 2011 [7] and despite the ambitious desire to increase forest area by 100,000 Hectares (ha) by 2030 [8], has created just 3,500ha of new woodland between 2010 and 2016 [9]. The Welsh forest industry must be incentivized by a larger market for timber products, thus the construction industry could help to link demand for new woodlands, while showing the capacity of wood to be utilized within high performance building. Through the mechanism of demand and supply, more trees will be planted, acting as carbon sink which helps to reduce the climate change disastrous effects. In addition, there is an increased need to drive efficiencies in housing supply and performance with the current and future skills shortages in the UK construction industry (as articulated in the Farmer Review – Modernise or Die) and is helping to encourage a shift to OSM [10]. In 2016, the TF construction method accounted for 30.7% of all new builds recorded in Wales [11], with a total capacity of 2990 units/year, generating £28 Million, and a willingness to expand to over 4300 units [6]. The WG's Innovative Housing Programme (IHP) introduced in 2017 with £100 Million is helping to greatly incentivise the shift to OSM in Wales, by funding 100% of the cost of innovation [12]. The advantages of OSM over conventional construction of housing includes quicker completion, greater quality of finish, less defects and minimal on-site duration [13]. Performance tends to be much nearer to design aspirations than conventional construction techniques [14]. The move to OSM and increased systemization is requiring a profound re-think of how is conceived and delivered industrialized housing [15]. In 2018 open panel TF systems accounted for around 71% of the total market and is the largest proportion of UK timber production, followed by closed panel TF systems (11%) [16]. Therefore, it is necessary to recognize the current structure of the manufacture while assessing the Welsh OSM timber construction systems in use, with a focus on engineered timber solutions for the building fabric i.e.

exterior walls, floors, ceiling and roofs in innovative homes. One pan Wales's wide research project that is attempting to disrupt the thinking around using timber grown and processed in the UK for OSM is the Home-Grown Homes project.

## 3 Home-Grown Homes Project

WKW was appointed in 2018, in partnership with the SuRBe group at Cardiff Metropolitan University (CMU), Timber Research and Development Association (TRADA) and Coed Cymru, by Powys County Council (PCC) to lead the delivery of an ambitious exemplar construction programme to provide demand-led stimulus for forest sector development in Wales: the HGHP. The HGHP represents the next development of the entire Welsh timber supply chain with the objective of creating jobs in growing, harvesting, processing and manufacturing of homes from natural timber resources. HGHP is funded by Welsh Government through the Rural Development Programme [17] and aims to build an important collaboration with building clients, developers, contractors and the timber supply chain, providing a compelling business case for expansion of timber construction while driving the growth of local OSM and the use of home-grown timber [18]. The HGHP has seven work packages (WP) with WP4 aimed at 'More and better local manufacturing' that is led by TRADA in conjunction with the SuRBe group at Cardiff Metropolitan University, see here for more information [19–21].

## 4 Home-grown homes project work package 4 and KESS2

WP4 of the HGHP is supporting the business case for increasing the volume and quality of construction systems supplied from Welsh manufacturers using home-grown timber [ibid]. The central feature of WP4 is to explore opportunities to increase systemization and standardization of Welsh manufactured solutions for improved cost and performance outcomes. The position of the TF OSMs in Wales is discussed in this paper following an evaluation between June 2018 and March 2019, by the authors of this paper. The KESS2 PhD study being undertaken by the first author aims to learn from the literature published on OSM using timber, and also the TF sector in Wales in order to develop a Pattern Book (PB) for developers of affordable dwellings for rent and sale that achieve nearly zero energy to zero energy dwellings. The PB to be produced by the KESS2 project [19,21], is in two parts. Part one of the PB (PB_1) is to model/calculate and validate thermal bridge details for two types of TF OSM exterior wall systems: a). a closed panel with synthetic non-breathable insulation manufactured by Sevenoaks Modular [22] b). a closed panel with natural breathable insulation, the OSM is yet to be confirmed. The development of PB_1 is being undertaken between April 2019 and December 2019. Part two of the PB (PB_2) is to conduct dynamic thermal modelling using the validated thermal bridge details from the two TF OSMs, for three dwelling types, which are forecasted to be in demand across Wales and to be developed by the housing association partner (Wales and the West Housing Association) in order to

achieve nearly zero energy and zero energy standards from 2020. The development of PB_2 will be undertaken between January 2020 and May 2021.

## 5 Evaluation methodology

In order to evaluate the TF OSMs operating in Wales, the researchers used a multi-methodological approach after Dainty [23] to collecting both qualitative and quantitative data. The research has established the key characteristics of the sector, identifying what is manufactured from timber in Wales and, at the same time, obtaining the manufacturers views on the future of the industry. Three different methodologies have been used, after ethics approval was granted by CMU in 2018. These included, firstly a desktop study which developed an assessment matrix to evaluate the main features and innovation of Welsh TF OSMs through their websites, to identify key features and to collate the sample population to investigate. Secondly, five organisations were selected for interviews to cover a diverse group in terms of company age, size, location and customer base, and part of a pilot study for the OSM operating in Wales. Availability of Directors at each sample has been an important criterion for selection, since most of the population identified in the desk-based interview were not interested or too busy to be interviewed. In order to collect what is often tacit knowledge the interview process was expected to take between two to three hours, to include also a guided tour of each OSM's facilities and production line/s. The questionnaire (with 13 open questions) used in the interviews sought to identify data about the organisations and their work as well as opinions about the challenges and opportunities ahead. The interview questionnaire was designed to capture both quantitative and qualitative information, allowing comparative analysis and enabling a specified structure of answers within the freedom of speech left to the participant. Thirdly, a questionnaire was developed, delivered by email and completed without the researchers present. This second questionnaire included refined/additional questions following the analysis of the results of the pilot stage (two) and was developed due to the budget and time constraints of the KESS2 project, as typically half to one day was taken in the second stage data collection with up to four researchers present. In particular this second questionnaire allowed specific queries about lean practices, collaboration with the other supply chain actors, barrier to further expansion, quality checks, availability of specific competences and machines, sustainability measures in use, future development plans. The questionnaire was articulated in 18 structured closed question, with possibility to insert comments. The final investigation phase aimed to cover a larger example of the population, enabling the researcher to draw general conclusions on the state-of-the-art of the Welsh TF OSMs.

a range of screening techniques have been used and the selected 36 from a possible 56 TF OSM's in Wales were identified. In summary the screening included identifying members of trade bodies, such as the Structural Timber Association (STA) and TRADA; then analysis of websites and testing phone numbers, plus purging organisations that traded under several brands. The total number of independent and active TF manufacturer in Wales selected with the filtering operations specified was 36.

## 6 Results

The results of the three phases has shown that TF OSM organisations in Wales, have operated up to 25 years and are classifiable as small to medium size enterprises (SMEs). These SMEs tend to work with low profit margins (around 3/4%) and thus without any significant investment in innovation and research. They are linked to the traditional TF offsite techniques, such as TF panelling with/without insulation and without any finished linings applied [24], and completely detached to the modern industrialized automated process seen in the more advanced Scottish manufactures [25]. It appears that the pace of change in the sector has been slow and marginal, with small tweaks to design and/or manufacturing methods rather than significant innovation in product or process. As consequence, it can be argued that significant changes are often driven by cost savings or a need to comply with new regulations. The Welsh TF manufacturers can offer different services: from manufacture of planar elements (consisting in roofs, walls and floors and deemed the main construction typology used in Wales) to delivery and erection of the production with specific transport/lifting equipment. The production is mainly focused on open and pre-insulated panels but there are some relative product innovations: Close panel technology is becoming established and produced, but still in very few manufacturers; Modular/volumetric house production starts to be used on specific project where high performance and continuous repetitiveness are required. The manufacture of such products is linked to the building typology to be constructed and to the speed of construction required. Too often the approach required by customers prevents any kind of realistic systemisation, standardisation or repetition in design and manufacture, so each project is effectively bespoke, requiring a tailored manufacturing process each time. A bespoke solution is inevitably more time consuming to set up and carry out, making it difficult to achieve any economy of scale.

It is apparent that there is a serious lack of knowledge about timber and TF manufacturing outside of the sector – clients, designers and funders seem to fail to see its added value and as a result do not value its potential. This is the reason why the manufacturer is involved at the end of the design chain, rather than near the start. So, for example, customers who want a TF delivered 'as soon as possible' or have already laid a foundation slab before approaching a manufacturer appears to occur in many projects, confirming that the TF OSM is one of the final design choices in the construction of buildings using timber in Wales. This behaviour prevents any real influence over design and specification and often sees the discussion focus more on cost than on quality. Consequently, the manufacturers are only building what they have been asked to. Early engagement with manufacturers would help improve the quality of the end product.

The manifested fear for new investment seems due to the Welsh TF construction market share, accounting for 30.7% accordingly to the STA statistics during 2016 [11]. Further uncertainty is brought by Brexit and the consequent repercussion on the timber supply market after the closure of the EU border [26].The risk of higher importing cost and the effect on sterling is believed of great impact on the actual raw timber market. The British timber market is heavily dependent on import and scarcely supplied with native trees. A lot of improvements are needed on the forestry side, increasing the woodland cover. The importance of creating and sustaining a consistent flow of activity

for manufacturers and their employees is important and crucial for any kind of effective production process to succeed. As result, the cashflow needs to be maintained and business investment decisions are to be made.

Finding people with the right skills needed is a challenge; principally in TF design but also in erection, when sub-contracted. Manufacturers report difficulties in accessing good quality groundwork services and often must spend a great deal of time packing and adapting frames before or during erection on site. Consequently, there are various discussions taking place with organisations which might be able to help meet the skills gap through apprenticeships, training and employment support [27] but these are yet to mature. Some manufacturers are large enough to employ their own high skilled professionals: designers and structural engineers are growing their own talent with practice, although there is a perception that TF manufacturing suffers from the same negative perception of boom/bust construction industry cycles, struggling to attract young people. Manufacturers said that a long-term commitment from Government to fund for example social housing and/or TF skill development programme was key to confidence.

The design, when delivered by the in-house team or by subcontracted specialized engineers, uses Computer Aided Design (CAD) specific software; the Building Information Modelling (BIM) method seems to be far from a daily use, but a lot of initiatives have been taken to satisfy regulation requests. The survey found little evidence of the use of BIM computer software tools with few manufacturers being asked to use it. However appear a range of bespoke and generic software and electronic solutions is being employed to design and then manufacture frame components. There is little sign of widespread use of tablets on site for inter-communication and updates with the OSM.

The manufacturing processes happen without Computer Numerical Controlled (CNC) machines assistance nor any degree automation, exception made for one manufacturer which showed on the shop floor an automated CNC (computer numerical control) cutter; the production hardly relies on manual and semi-automatic machines controlled by skilled workers. All material used is PEFC (Programme for the Endorsement of Forest Certification) or FSC (Forest Stewardship Council) which represent the protocols adopted for wood and supply chain certification [28]. Those certificates ensure that the timber is purchased from well-managed forests and/or recycled materials, ensuring the sustainable harvesting of the trees. The manufacturers have shown little to no use of home-grown timber. Whist, there is interest in sourcing home-grown timber, it appears that there is only occasional demand from clients. This is as a consequence of supply problems, with most using timber from Scandinavia and Eastern Europe. The quality of home-grown timber in the past had been a concern for some manufacturers. It is also clear that the use of timber cladding, fascia's or windows is limited, with other materials perceived to be cheaper and lower maintenance. The importance of protecting TF immediately after manufacture, during delivery and erection against the consequences of poor weather (typical in Wales, with driving and prolonged spells of rain) would appear to vary. Storing of raw materials and manufactured TFs occurs to be generally external without coverage, exposing the production to the weather and potentially damage, even though the panels are deemed safe because protected by the membrane applied, acting as perceived water barriers. In exposed conditions, timber can reach a

moisture content higher than the equilibrium moisture content. As opposite, when installed, moisture will be desorbed which can cause wood to shrink, resulting in dimensional changes that can harm the performance [29]. There are examples where some of the manufacturers store the raw timber and manufactured TFs under cover. As result, for some manufacturers there are limitations on the space available for storage or growth, where delays in construction programmes mean that even with just-in-time delivery TF stock is often outside under the weather awaiting delivery to site for up to six months. At the same time, moving a business to larger premises comes at a cost and brings risks if the market declines.

The OSM TF industry could gain substantial improvements in efficiency including lean concept within the production [15]. In 2019, Welsh manufacturers use a basic lean approach. The customization seems to be matched by all the manufacturer specificities, which offer to the client an 'ad hoc' product, considering the performance required (e.g. thermal, structural, acoustic, fire, etc.). The shop floor is flexible and adaptable to case by case solutions; the semi-skilled to multi-skilled workforce can customize and respond to unplanned changes and continuously improve the process through practice. The reduction of timber waste is not always managed; only one of TF manufacturers used a combined heat and power boiler, which burns factory wooden by-products to produce heat and to dry fresh green chipped wood, while electricity power is used to feed a small extent of the factory machines. Just-in-time production concept are apparently adopted by few manufacturers, who produce, deliver and erect subsequently; this process seems not to be perfectly implemented, as the manufacturers still require large stocking space or anyway keep a lot of the production and supplied product in the yard stocking space because of last minute site delays. Transfer concepts of lean production from manufacturing to construction is still difficult because of the great variety of products, but not impossible: the TF industry need to be more efficient and better organized to supply the future housing requests. Standardization, quality control and reduction of uncertainties [30] seem to be a prerequisite to build affordable and efficient houses.

To improve the performances of the industry in Wales, it is necessary to develop a close collaboration with research, supply chains and academic institutions. Some manufacturers already collaborate proactively with other manufacturers and with constructors, building solid and long commercial relations, based on workloads and niche jobs, where the adaptation of the shop floor is not convenient. This reflects the outcome of a Finnish study [31], where manufacturers have shown particular reluctance for change and risk-taking operations. Only one of the sample was collaborating with a University, in a three year Knowledge Transfer Partnerships (KTP) project aiming to improve competitiveness and productivity through the better use of knowledge and technology [32]. This kind of experiences are necessary in a slow changing sector like construction and useful to build up the knowledge to deal with problems and move forward the industry.

## 7 Discussion

The TF OSM industry Wales appears to be stuck in the middle of a highly competitive procurement route, driven by low cost and late engagement from clients, but demanding

quality and speed. There is often friction between TF OSM's and their clients, leading to many challenges and creating buildings with compromises. Many projects are not designed with TF in mind and are converted in final design decisions. At the same time, late changes obstruct the workflow and create waste [30], reducing some of the TF benefits and making structural design of the building unnecessarily more difficult and expensive. Contract terms stacked against TF OSM's by their clients and payment delays expose them to risk, particularly should the client get into financial difficulties. It is important that the Welsh TF OSM's builds bridges with buildings contractors and developers, so that they understand the benefits they can offer, how it fits alongside other trades and how efficiencies and performance can be realised. TF OSM's has so much more to offer the client if early engagement and collaboration are possible. End users of buildings often do not know or care what construction systems are adopted or understand the benefits that TF can offer. If, through education, clients could be led towards specifying TF OSM, further benefits for all involved could be realised. Recent examples of some UK based TF manufacturers partnering with housing associations and developers demonstrate that this is possible [33].

The drive towards Modern Methods of Construction (MMC) means that parts of buildings made in a factory will be arriving on site to a standard of finish and tolerance that the construction industry is not used to, in the UK. Site alterations are necessary to fit and avoid exposure to weather or slow construction adding cost. All sectors of the wider construction industry will need to improve procedures to meet these new challenges presented by the TF needs, to be more proactive for the long-term benefit of the product. With an ageing workforce and the demand for more homes to be built every year, the construction industry is slowly walking into an impossible situation. Carrying out repetitive tasks in a factory environment where quality can be managed and site skills reduced may offer the answer. Many items made in factories are mass produced, however although some developers use standard house types, many buildings are unique. This leads to less efficient factory production and a higher risk of mistakes as each building becomes its own prototype. There is great potential for lean production methods used more generally in manufacturing to be applied to TF factories [30]. TF has been built in factories for many years and is well placed to raise its market share, particularly if it can move to the next level of factory production.

There is currently little excitement about using Welsh timber in the TF industry as long as it is timber of adequate strength and quality. If the food industry can create a demand and premium for a home grown offering [34], there is a potential through marketing of local timber to do the same. Some self-builders who have access to local timber go to great lengths to use it and feel better for the experience. Further work on the forestry side is needed to ensure that supply can sustain future demand. With short term costs and regulations driving innovation, changes are often slow in the construction industry. New government legislation such as the recent announcement that gas boilers and hobs will be banned from new properties from 2025 [35] will see rapid changes in building fabric performance and TF is well placed to capitalise on these. If we can educate clients and contractors, demonstrate performance and create a demand for home-grown timber, the buildings of tomorrow could be entirely TF. Findings of the

engagement with the TF OSM's are informing the development of the PB in collaboration with Wales' largest developer of affordable homes [36] and one TF OSM [32].

## 8 Conclusions

This paper has given context and explicated WP4 of the HGHP and the KESS2 doctorate study, both of which are investigating the challenges in using home-grown timber to deliver high quality, high performance and healthy homes for Wales. The findings from the survey will be used in the following phases of the project where the author will review different OSM systems in terms of cost, building performance, and the applicability to the Welsh context in terms of housing requirement and potential for the use of home-grown timber now and into the future. Next challenges and phases of the KESS2 project have been discussed as well as the potential outputs.

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## 10 References

1. EC. Innovating for Sustainable Growth: A Bioeconomy for Europe. Ind. Biotechnol. 2012.
2. UNFCCC. UNITED NATIONS Climate Change Summit. United Nations; [cited 2019 May 15]; Available from: https://www.un.org/en/climatechange/un-climate-summit-2019.shtml
3. EC. Roadmap to a Resource Efficient Europe. 2011 [Internet]. 2011; Available from: http://ec.europa.eu/
4. WG. The Well-being of Future Generations (Wales) Act 2015. 2015.
5. WG. Woodlands for Wales. The Welsh Government's Strategy for Woodlands. 2018.
6. EGAN consulting. Timber frame housing manufacture in Wales and its capacity and capability. 2017.
7. Forestry Commission. NFI 2011 woodland map Wales. 2011.
8. Osmond J, Upton S. Growing our woodlands in Wales. 2012.
9. National Assembly for Wales. The Welsh Government's progress on climate change mitigation: Annual Report of the Climate Change, Environment and Rural Affairs Committee. 2018; Available from: www.assembly.wales
10. Farmer M. The Farmer Review of the UK Construction Labour Model [Internet]. 2016. Available from: https://www.gov.uk/government/publications/constructionlabour-%0Amarket-in-the-uk-farmer-review.
11. Structural Timber Association. Annual survey of UK structural timber markets The UK housebuilding market 2016. 2017;
12. WG. Innovative Housing Programme (IHP). 2019;3:0–20.
13. Pan W, Gibb A, Dainty A. Offsite Modern Methods of Construction in Housebuilding Perspectives and Practices of Leading UK Housebuilders. Strategies. 2005;

14. Hetherington D. Delivering New Homes – A Future Off-site? [Internet]. Northen Hous. Consort. 2016. Available from: https://www.northern-consortium.org.uk/2016/04/29/delivering-new-homes-a-future-off-site/
15. Höök M. Lean Culture in Industrialized Housing - a study of Timber Volume Element Prefabrication. Environ Eng. 2008;
16. STA. Timber Frame Construction Market UK. 2019.
17. Arwain. Home Grown Homes [Internet]. 2018. Available from: http://www.arwain.wales/en/news/archive/article/home-grown-homes.html
18. Newman G, Binding T. Feasibility Study for the development of the Home-Grown Homes Supply Chain Development Service. 2017.
19. WoodKnowledge Wales. The Home Grown Homes Project [Internet]. Available from: http://woodknowledge.wales/prosiect-cartrefi-o-bren-lleol-home-grown-homes
20. Littlewood JR, Zaccaro F, Wilgeroth P, Whyman T, Karani G, Evans N, et al. Systemised offsite manufactured timber dwelling typologies from UK forestry supply chains, a transition to nearly zero carbon homes in Wales. Smart Innov Syst Technol. 2019;131:425–34.
21. Zaccaro F, Littlewood J, Wilgeroth P, Whyman A, Newman G, Lancashire R, et al. An introduction to systemised offsite manufactured and engineered timber dwelling typologies from welsh and uk forestry supply chains, enabling transition to nearly zero carbon homes in Wales. Sustain Ecol Eng Des Soc Conf. Dublin; 2018. p. 734–42.
22. BBA. Prefabricated timber frame panels - Triso-warm external wall panels. 2016.
23. Dainty A. A Call for Methodological Pluralism in Built Environment Resarch. CIB World Congr Build a Better World. 2010;Postgraduate Plenary Lecture.
24. Hairstans R, Sanna F. A Scottish perspective on timber offsite construction. Offsite Archit Constr Futur [Internet]. Taylor & Francis (Routledge); 2017. Available from: http://researchrepository.napier.ac.uk/Output/931004
25. CCG Construction and Manufacturing Group | CCG [Internet]. [cited 2019 May 15]. Available from: http://c-c-g.co.uk/
26. Michael P. What will be the impact of BREXIT on the UK Construction Industry ? :5–6.
27. Welsh Government. Woodlands for Wales Action Plan [Internet]. 2016. Available from: http://gov.wales/docs/drah/publications/160223-woodlands-for-wales-action-plan-en.pdf
28. Coulson J. Sustainable use of wood in construction. Int Wood Prod J. 2014;
29. Shmulsky R, Jones PD. Wood and Water. For Prod Wood Sci. 2019;141–73.
30. Johnsson H, Sardén Y. Industrialised timber housing: From trial to production. Assoc Res Constr Manag ARCOM 2008 - Proc 24th Annu Conf. 2008. p. 155–64.
31. Hurmekoski E, Pykäläinen J, Hetemäki L. Long-term targets for green building: Explorative Delphi backcasting study on wood-frame multi-story construction in Finland. J Clean Prod. 2018;172:3644–54.
32. Littlewood JR. Innovative Construction & Offsite Manufacture – Trisowarm [Internet]. 2019. Available from: https://surbe.org/innovative-construction-offsite-manufacture/
33. McColgan C. Work Starts on £10 Million Cardiff Social Housing Development [Internet]. 2018 [cited 2019 May 14]. Available from: https://businessnewswales.com/work-starts-on-10-million-cardiff-social-housing-development/
34. More People. MorePeople | 7 in 10 UK consumers want homegrown produce [Internet]. 2018 [cited 2019 May 14]. Available from: https://www.morepeople.co.uk/knowledge-centre/article/7-in-10-uk-consumers-want-homegrown-produce/801845826
35. Roger Harrabin. Gas heating ban for new homes from 2025 - BBC News [Internet]. 2019. Available from: https://www.bbc.co.uk/news/science-environment-47559920
36. Welcome to Wales & West Housing [Internet]. 2019 [cited 2019 May 15]. Available from: https://www.wwha.co.uk/